HISTORICAL USE OF GPS IN WASHINGTON STATE
Background of GPS at WSDOT, by Kurt Iverson

The Washington State Department of Transportation (WSDOT) has been using the Global Positioning System (GPS) since 1985 in conjunction with conventional surveying and coordinate geometry (COGO) techniques for the purpose of controlling various maps for right of way, record of monumentation, alignments for design and construction and Geographic Information Systems (GIS).

During the past ten years, the utilization of GPS Technologies within WSDOT has been limited to the Survey Section of Geographic Services. The few exceptions during this period have been the use of GPS (Trimble Pro SL receivers) by the Environmental Affairs Office, and the Transportation Data Office. Also, centimeter level Real Time Kinematic GPS topographic surveys are on-going in the Eastern Region near Spokane. Recently the South Central Region, based in Yakima, purchased four Leica survey grade receivers for controlling design projects. At this time, the demand to obtain GPS technologies and skills is increasing at the Regional and Headquarters level. This interest has been fueled by reductions in per unit costs of GPS receivers at all levels of positional accuracy's and a greatly expanded knowledge base of applications/techniques that provide geospatial data at cost reductions that far exceed any traditional positioning methods. Under the current de facto implementation of GPS in WSDOT, the sole source of geodetic, mark maintenance and photogrammetric quality surveys (accuracy's in centimeters) are limited to the cost recovery activities of the Geographic Services Survey Section.

The Transportation Data Office (TDO) has purchased two GPS receivers for video logging and geospatial attribute data collection (roadside hazard). The Data Office use of GPS is at the Geographic Information System (GIS/Resources Mapping level accuracy, sub-meter to five meters). Data collected is most often post-processed, however, real time GPS applications utilize CORS and OMNISTAR systems. The Environmental Affairs Office is using like equipment for inventory of wetlands and other environmental features. As the use of GIS becomes more prevalent within the Department, the proliferation of GPS receivers involved in GIS data collection may likely exceed, numerically, the units employed for geodetic and construction surveying applications.

The first GPS survey of significance in Washington State was performed by the National Geodetic Survey (NGS) in 1985. The work was performed under contract by WSDOT’s Photogrammetric Branch (renamed Geographic Services). In the following years, GPS users realized the published values of the National Geodetic Reference System (1:100,000) were not of sufficient accuracy to accommodate the high level of precision inherent within the GPS system. A GPS Users Group was formed in 1988, (spear headed by NGS Advisor, Dennis Wegenast), to address the feasibility of a Washington State High Precision Network (HPGN) that would upgrade and readjust coordinates of the geodetic control stations representing the North American Datum of 1983 (NAD83). In 1990, an Order B survey (1:1,000,000) was performed with GPS by the NGS and funded by a coalition of state and federal agencies, cities, counties, and other private entities. Very Long Baseline Interferometry (VLBI) was included in the survey for the purpose of global reference. The acronym HPGN then evolved into High Accuracy Reference Networks (HARN) which is currently divided into Federal Base Networks (FBN) and Cooperative Base Networks (CBN).
Upgrades to the Washington State HARN were performed in 1998 as data from Continuously Operating Reference Stations (CORS) provided improved ellipsoid height determination. Four CORS sites located at Fort Stevens on the mouth of the Columbia River, Appleton at the east end of the Columbia River Gorge, Point Robertson on Vashon Island, and the Naval Air Station on Whidbey Island were used as base fiducial stations as Order A (1:10,000,000) GPS surveys were performed on FBN stations and Order B (1:1,000,000) GPS surveys were performed on CBN stations.
Because the increased number of GPS users and the appeal of increased accuracy of elipsoid heights, the

Washington State GPS Users Group supported the re-observation effort by again putting together a coalition of state and federal agencies, cities, counties, and various public and private entities to assist the NGS in the HARN re-observation. Cooperative efforts in the 1998 HARN survey was directed by NGS Advisor, Gary Perasso. Trimble geodetic quality dual-frequency GPS equipment was used exclusively throughout all groups for all observations. As the re-observed HARN station values become available, Geographic Services Survey Section will readjust WSDOT coordinates accordingly.

Geographic Services Survey Section

The WSDOT Geographic Services Branch is managed by a team consisting of one supervisor each from the Aerial Photography, Photogrammetry, Cartography, Geographic Information Systems, and the Survey Section.

The Geodetic Survey Section's Mission Is:

To provide geodetic primary control throughout the state as required for WSDOT projects and act as a resource center to the public for geodetic information. The purpose is to achieve monumentation of Washington's highways by ensuring that the Departments survey procedures: (1) preserve and perpetuate previously established monuments and (2) contribute to the body of public records (eliminate duplication of survey work) by establishing monuments and recording monuments that are tied to a state plane and to a standard vertical datum.

The Geodetic Survey Section's Vision Is:

To utilize the latest technology to maintain the Washington State High Accuracy Reference Network, the densification of primary control from it, and help to ensure that all divisions throughout the WSDOT are trained and equipped to fully utilize geodetic products in the interest of increasing quality and efficiency.

The Geodetic Survey Section's Values Are:

To maintain the highest standard of accuracy and precision possible, meeting requirements based on long term needs of the Department and it's customers.

The section is the only unit within the WSDOT providing primary geodetic surveys. The group is also the only unit within the state with the expertise and equipment to maintain the Washington High Accuracy Network (HARN), the geodetic framework for state legislated horizontal datum of NAD83/91 and federal mandated vertical datum of NAVD 88.

The geodetic field crew operates with 10 Trimble SSi GPS receivers with Real Time Kinematic (RTK) capability. All projects originate from the Washington HARN. Concrete monumentation is used as a standard for all primary control. Data reduction is accomplished on Pentium workstations and the output is backed up on magnetic and hard copy media. In addition to GPS information, the in house database consists of 2nd and 3rd order bar-code leveling as well as benchmark resets. All field work is done to FGCS specifications and classified to National Spatial Data Infrastructure (NSDI) standards. The database is available via Internet at www.wsdot.wa.gov/monument.

The Geodetic Survey section is currently involved with three important programs: Highway Monument Surveying, Primary Control Monument Program, and the Datum Point Adjustment and Archival Program.

Highway Monument Surveying Program

The objective of the Highway Monument Survey Program is to help maintain the monumentation of the geometric framework that is used for planning, design, and construction surveys by reestablishing and updating existing and establishing new primary control (including HARN stations and federal BM's).

Accomplishments of the 1997-1999 Biennium:

· Formed a partnership with the National Geodetic Survey to re-observe 120 geodetic control stations that consist of the Federal Base Network, a part of the National Spatial Reference System.

· Conducted research, inventory and verification of primary survey control for the purpose of building a database as the spatial framework for the department's Geographic Information System. More than 1,000 monuments were physically searched for, recovered, and updated or listed as destroyed.

· In addition to conducting several horizontal and vertical control surveys to upgrade geodetic networks where large distortions previously existed, six National Geodetic Survey Vertical Control elevation benchmarks were re-established.

Primary Control Monument Program

The objective of the Primary Control Monument Program is to implement a procedure that replaces a project-

by-project data collection system with a more cost effective systematic approach for supplying geodetic control along Washington's highways.
Datum point development is now based on a prioritization process using the "Plan for Highways of Statewide Significance" and 2, 6, and 20 year plans. Increased quality and savings are gained as protracted lengths of highways are densified as one project rather than a series of smaller projects. Technically, large survey network adjustments are superior to that of forcing the adjustment of a succession of previously unconnected small projects. It is estimated that the department can increase the amount of datum points by 35% if datum point information is collected on a planned, sequential basis.
The Primary Control Monument Program has been a valuable asset to WSDOT and it's customers as it provides the base frame for environmental mapping of Salmon Habitat Rehabilitation, Noise Wall/Air Quality, Wetland Land Bank, as well as, for Design, Construction, Right of Way delineation, Geographic Information, and Maintenance Inventory of Infrastructure.
Since July 1999, prioritized GPS geodetic projects networking all of Spokane, Pend Oreille, and Stevens counties as well as large segments of Kitsap, Grays Harbor, Pacific, Thurston, and Pierce counties. These projects, which have produced some 218 Order C monuments, were scheduled and surveyed in advance of engineering for environmental, design and construction. The spacing and density of control lends itself to serve as targeted mapping control for photogrammetric reconnaissance missions, as well as for secondary surveys supporting land surveys and construction. All of the data output is available to the public and private sectors via the Geographic Services Monument Database on the Internet.
As related to the WSDOT's Strategic Plan, the Primary Control Monument Program:
· Further enhances "Public Confidence" by improving an already popular survey datum point and database program. Currently, 50% of users will be experiencing an estimated 35% increase in the number of needed and available datum points.
· Redefines "Roles and Responsibilities" as resources are transferred to more effectively meet state transportation needs. Also, pursues "technical excellence" by utilizing large network adjustments that are superior to that of a succession of previously unconnected small projects.
· Enhances stability throughout the biennium, rather than a highly fluctuating and stressful work environment, and insures the success of a diverse "core workforce" capable of responding to peak needs.
· "Maximizes the use of existing funds" by emphasizing efficiency though better planning.
Datum Point Adjustment and Archival Program
Scientific and technical advancement have prompted the National Oceanic and Atmospheric Administration (NOAA) to upgrade the coordinates and heights of the federal reference system WSDOT employs to provide primary datum point information for highway construction projects and resource management.
In the interest of maintaining consistency with state law (RCW 58.20, WAC 332-130), federal regulation and departmental standards, the Geographic Services Survey section must utilize current reference systems upgrades when surveying for new construction projects. As a result, a total of 700 survey projects, consisting of 4,000 WSDOT primary datum points, will need readjustment on an individual basis in order to satisfy legal requirement. Development of a GPS Vector Information Database will eliminate the need to readjust individual projects for this purpose in the future.
As related to the WSDOT's Strategic Plan, the Datum Point Adjustment and Archival Program:
· Best serves the public's interest by using a visionary and innovative method to solve an ethical and legal engineering problem. Agency accountability is improved by the ability to efficiently comply with requirements of RCW 58.20 and WAC 332.130.
· Further enhances public confidence as legal responsibilities are addressed and expertise or resources move swiftly to meet state transportation needs.
· Emphasizes efficiency, resulting in future cost avoidance while maximizing the use of existing funds. Anticipated periodic changes in the federal reference system will be manipulated 83% more efficiently with this improvement.

Utilizing GPS for Geophysical Studies in the Pacific Northwest
The landscape of the Pacific Northwest is shaped by processes of plate subduction offshore, uplift of the

Cascade Range, Cascades, and Columbia River Plateau volcanism, and Basin and Range faulting. Although these processes operate at slow rates, building obvious structures only over "geologic time", modern surveying methods utilizing GPS satellites may discern deformation due to these processes in just years. With a goal of measuring millimeter-scale displacements within the Pacific Northwest region, a collaborative project known as the "Pacific Northwest Geodetic Array" or PANGA. This team has deployed an extensive network of GPS tracking sites which is measuring tectonic activity in the region.

The need for a permanent GPS array in this region has long been recognized. Geodetic results from twelve new permanent GPS sites installed as a part of the array are being integrated with existing sites and analyzed at Central Washington University (CWU) using software tools developed by the Jet Propulsion Laboratory (JPL) and NASA.

Geodetic and geologic results from CWU will be used to constrain two-dimensional Kinematic modeling and three-dimensional geodynamic modeling of the western U.S. A data analysis facility developed at CWU will reduce and distribute on-line and CD-ROM geodetic data products to the geophysical community.

Diverse sources are supporting installation and operation of the GPS network. Funding for six or more CWU receivers and five University of Washington (UW) receivers is currently in hand as part of a recent NSF-ARI initiative to disseminate GPS technology in a "Geodoscope" of related networks that monitor Pacific Rim tectonic processes on greatly improved scale and spatial resolution. Most of the receivers will be used in permanent sites, but at least one from each university will be put into a monthly rotation using campaign strategy called Multimodal Occupation Strategy (MOST).

CWU, UW, and the United States Geological Survey (USGS) will maintain the network over the life of the current proposal. The USGS is developing support for long term network maintenance, with CWU committing to permanent technical data analysis beyond the current proposal.

All monuments are drilled, braced, and are deeply anchored. The monument consists of a vertical, schedule 80, galvanized pipe mounted in non-shrink grout in 4.5" diameter hole drilled to approximately 40 feet deep, laterally stabilized by four additional rods welded to the top of the monument, each anchored to a minimum depth of 40 feet in 4.5 inch diameter holes. Each anchor hole will be cased in the upper 12 to 14 feet with 2.5 inch diameter schedule 80 PVC wrapped with ¾ inch thick refrigeration foam protected by layers of strapping and duct tape.

The GPS instrumentation used are Trimble Ssi receivers with choke ring antennas mounted on stainless steel recoverable plates modified by JPL and Scripps. Plexiglas radomes geometrically centered on the phase center of the antenna, while the antenna cables are buried and encased in liqutite conduit or as liqutite armored cable. The conduit and cable connections are protected by encapsulated shrink tubing.

All of the sites have secure and covered facilities, with NEMA/EEMAC Type 1 enclosures with bulkhead fittings. The enclosures contain the Trimble receiver, US Robotics 56 Kbs modem, Trimble OSM, and heavy duty surge protectors.

Operating Institutions of PANGA are:

· Department of Geology, Central Washington University
· University Pacific Geoscience Center, Geological Survey of Canada
· College of Atmospheric and Oceanic Sciences, Oregon State University
· Cascade Volcano Observatory, U.S. Geological Survey
· Geophysics Program, University of Washington

Collaborating or Participating Institutions:

· University of Alaska, Fairbanks, AK
· Department of Geology and Geological Engineering, University of Idaho
· Department of Geological Sciences, University of Oregon
· University of Navstar Consortium

Supporting Program:

· Department of Natural Resources, Canada
· National Earthquake Hazards Reduction Program, U.S. Geological Survey
· National Science Foundation

Other Public and Private Entities

Other state agencies using GPS for surveying purposes include the Department of Natural Resources, Department of Ecology and Department of Fish and Wildlife. Primary uses of survey grade GPS at Natural Resources and Fish and Wildlife are cadastral related. These two agencies are heavily involved in conducting boundary surveys of public land. GIS applications are heavily supported by GPS throughout state government. The Department of Ecology has recently completed a joint GPS project, with the United States Geological Survey (USGS). The purpose of the survey, which included an 80 mile geodetic network along the Pacific Coast, was to monitor the increasing problem of beach erosion. Geographic Services was instrumental in designing the network which implemented N.G.S. Height Modernization Program procedures for 2cm accuracy for ellipsoid height. The monuments along the shoreline were set at approximately 2 to 4 mile intervals and were designed to act as fiducial marks for Real Time Kinematic GPS operation to profile tidal zones and nearby uplands.

In addition to these state agencies, federal users such as U.S. Forest Service, Bureau of Land Management, and Bonneville Power Administration actively use GPS for land surveying purposes. City and county organizations are also actively involved in utilizing GPS to tie local cadastral systems to the National Spatial Reference Network for GIS purposes.

The private sector surveying and engineering firms utilize GPS survey and resource grade receivers for multitude of applications ranging from geodetic surveys to inventory surveys.

The proliferation of GPS receivers involved in GIS data collection (sub-meter resource grade) is exceeding, numerically, the units employed for geodetic, land boundary and construction surveying applications. The ability to efficiently collect spatial information on GIS related features has been the driving force behind every GIS/spatial product. With the advent of CORS stations in Washington State, the use of Real Time Kinematic applications have risen sharply.

Conclusion

The use of GPS in Washington State began early (1985), when GPS technology development was at its infancy stage. Washington State was one of the first half a dozen states to form a GPS Users Group under guidance of the National Geodetic Survey Advisor Program and produce a High Precision Network. Today, the use of GPS in Washington State is common place.

The challenge GPS users face today is not how to utilize the technology or how to process the data, but rather, how to maintain a system of datum references and data bank systems in which to store GPS information. The 1998 NGS/HARN reobservation project and high number of volunteers is a great example of how important increasing the accuracy of 3D geodetic references have become. The advent of CORS stations has played a significant role in developing increased accuracy, especially in ellipsoidal height determination - key to the height modernization process. The CORS ability to provide DGPS real time signals are instrumental in development of many GIS mapping applications. These benefits are, of course, additions to the original intent of providing a navigation service.

As the number of CORS stations increases the amount of applications will increase also. Until the recent addition of CORS site at Appleton, the eastern half of Washington State had no provision for real time applications which severely impact many GIS operations. The further additions of CORS stations at proposed sites in Spokane and Wenatchee will be welcomed by most all GPS users in Washington State.

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